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CAMBIAL ELECTRICAL RESISTANCE IN THINNED AND UNTHINNED LODGEPOLE PINE

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FINAL REPORT

Cambial Electrical Resistance in Thinned and Unthinned Lodgepole Pine

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CAMBIAL ELECTRICAL RESISTANCE IN THINNED AND UNTHINNED LODGEPOLE PINE

INT/UM Research Joint Venture Agreement No. INT-89404-RJVA
Final Report

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INTRODUCTION

Foresters have long sought a reliable index of tree vigor, both as an indicator of growth potential and resistance to biotic and abiotic stress. Factors such as crown ratio, density, and form have traditionally been used as visual manifestations of tree vitality (Dunning 1928; Taylor 1937; Schmidt et al. 1976). However, growth performance indices such as the ratio of growth increment to leaf area or sapwood area (Waring et al. 1980), or measures of physiological status, such as starch content (McCullough and Wagner 1987) or plant water potential (Scholander et al. 1965), may provide a better index of vigor than visual attributes (Kaufmann and Watkins 1990). Because previous studies have shown that carbon allocation to the bole is lower priority than root or shoot growth (Gordon and Larson 1968), bole increment should provide a measure of tree vigor (Waring et al. 1980).

Electrical properties have also been investigated as indicators of the physiological status of trees. Electrical

resistance (ER) and capacitance have received particular attention because they can be measured *in situ*, with negligible effect on tree condition. For example, ER has been used as a general indicator of plant vigor (Wargo and Skutt 1975; Shortle et al. 1977). It has also been used as an index of susceptibility to insects (Davis et al. 1980; Matson et al. 1984) and disease (Blanchard and Carter 1980), and as a measure of the effect of cultural treatments on vigor (Smith et al. 1976; Piene et al. 1984). Several authors have documented the potential of using ER measurements in making thinning decisions for specific or limited applications e.g. leaving high vigor sugar maple for syrup production (Shortle et al. 1979), or for eliminating subjectivity when imposing experimental thinning treatments (Blanche et al. 1990). Kostka and Sherald (1982) recommend further analysis of ER as a measure of vigor in different species and cultural situations to determine its practical value in management.

A primary objective of this study was to determine the relationship between ER and other tree attributes (particularly those used as indicators of vigor), and whether these relationships were consistent between thinned and unthinned stands.

METHODS

Study Area

The field portion of this study was conducted in conjunction

with a companion study of lodgepole pine susceptibility to the mountain pine beetle (Dendroctonus ponderosae Hopkins). United States Forest Service (USFS) national forest system records for western Montana, northern Idaho, eastern Oregon, and northern Utah were screened to identify stands that met the following criteria: 1) ≥50 years old, 2) essentially pure lodgepole pine, 3) thinned between 1970 and 1987, and 4) either adjacent to or near an unthinned stand of similar age, species composition, and site. Not all qualifying stands could be sampled due to time limitations. Sample stands were drawn from the list of qualifiers, and should typify maturing lodgepole pine stands in the Northern Rocky Mountains and Inland West.

Field Methods

Six to nine variable plot centers were located in a grid pattern in each of the 20 thinned stands that were sampled. Three plot centers were located at equal intervals along a line approximately bisecting the unthinned stand adjacent to each thinned stand.

A Relaskop was used to select "in" trees for sampling around each variable plot center. Each "in" tree was classified according to crown class (i.e. dominant, codominant, intermediate, suppressed). Detailed measurements were taken on the two "in" trees closest to the plot center, and on the first "in" tree encountered clockwise from north for each crown class not represented in the closest two trees, if present. If the two

"in" trees closest to the plot center were from the same crown class (e.g. codominant), the potential maximum number of trees sampled on a plot was five; if they were from different crown classes, the maximum was four. Measurements included diameter at breast height (DBH - 1.37m), height, crown length, ER, and phloem thickness (PT). Two ER measurements were taken at DBH on each tree (north and south side) using a model 7950 Shigometer. ER measurements were taken to the nearest 0.5 k ^ by inserting stainless steel needle electrodes (vertically aligned) into the xylem. Trees measured for ER in a given thinned/unthinned stand pair were sampled consecutively between 12:00 noon and 3:00 pm of the same day, as recommended by Piene et al. (1984), to minimize variation in ER readings due to weather and time of day. Bark samples were extracted at breast height from the north and south side of each tree at the locations defined by the needle holes left from sampling ER. Bark sections were measured for PT using methods outlined by Cole (1986). In addition, each sample tree was cored at DBH for later determination of age, sapwood radius, past five-year radial increment, and five- and ten-year pre-treatment and post-treatment radial increment.

Increment cores were analyzed for age at breast height and annual increment with a microscope-assisted ring reader connected to a personal computer. Cores were stained with a five percent ferric chloride solution to verify the sapwood/heartwood interface previously marked in the field (Kutscha and Sachs 1962).

Analysis

Data analysis was conducted in three phases. In the first phase, the strength of the association between ER and PT and ER and DBH was estimated using correlation. Values of ER and PT used in the analysis were the means of the two samples (north and south side) from each tree.

In the second phase, multiple regression methods were employed to determine the effectiveness of tree and stand parameters and cultural treatment (thinned or unthinned) in explaining variation in ER. Individual tree parameters (i.e. PT, DBH, CR, and SA) used as explanatory variables in the analysis indirectly reflect tree vigor. Because the level of thinning was different in each stand (i.e. treatment was nested within stand), cultural treatment was introduced as a set of dummy variables (unthinned = 0; thinned = 1). Differences among stands were modeled by a set of dummy variables (one variable per stand) because it was assumed there was no substantial difference in the relationship between ER and the explanatory variables among stands.

Finally, principal components analysis was used to evaluate the relationship of the five parameters measured in this study that reflect some aspect of tree vigor; ER, PT, CR, SA, and five-year basal area increment (BA5). ER measures current water potential, or moisture status; PT is a measure of the tissue that conducts photosynthate; CR is a crude index of the foliage

available for photosynthesis; SA is a measure of the moisture conducting tissue in a tree; and BA5 is a measure of carbon accretion after respiratory needs have been met. Because observations on these variables were in different units, all observations were standardized prior to principal components analysis to allow comparability of results.

RESULTS

The correlations of ER to PT and ER to DBH are shown in Table 1. Correlations of ER with PT and ER with DBH were lower for the thinned than adjacent unthinned stands, presumably because tree water potential (as measured by ER) was not yet in equilibrium with PT or DBH following the thinning disturbance that occurred some years earlier.

Table 1. Minimum, 1st quartile, median, 3rd quartile, and maximum correlation coefficients from the correlation of ER:PT and ER:DBH for 20 unthinned and 20 thinned lodgepole pine stands.

	Corr. of ER with PT		Corr. of ER with DBH	
	Unthinned	Thinned	Unthinned	Thinned
Minimum	-0.952	-0.876	-0.957	-0.639
1st quartile	-0.809	-0.675	-0.865	-0.467
Median	-0.685	-0.393	-0.594	-0.264
3rd quartile	-0.328	-0.293	-0.300	-0.204
Maximum	0.338	0.289	-0.029	0.330

Several authors have reported a moderate correlation between ER and PT (Carter and Blanchard 1978; Cole and Jensen 1980; Matson et al. 1987), and ER and DBH (Wargo and Skutt 1975). In

this study, within-stand correlations between ER and PT and ER and DBH ranged from very high to low (Table 1). There are several plausible explanations for this difference. First, the wide range in correlation coefficients among stands was expected considering the broad range of locations, ecological habitat types, stand ages and densities, site indices, and dates (late June to early September) of measurement. Second, sample trees in some stands had the phloem and diameter attributes of vigorous trees, but may have been stressed due to seasonal weather conditions, advancing age, or current high stand density. From a vigor standpoint, PT and DBH are lag indicators (variables), in that they reflect past performance. For example, diameter reflects cumulative radial growth of a tree up to the time of measurement, and the phloem layer of mature lodgepole pine consists of an average of 25 years of annual phloem increment (Cabrera 1979). ER, in contrast, better reflects current tree vigor because of its established relationship with water potential (Dixon et al. 1978), and its sensitivity to water stress (MacDougall et al. 1987). Results of a study by Blanchard et al. (1983) relating ER to periodic growth rate in balsam fir suggested that ER readings are influenced by current year's growth only. Because current increment is often highly correlated with periodic increment, ER would be expected to be correlated with periodic increment as well. However, if a tree's water potential has declined recently, it is unlikely that PT,

DBH, CR, SA, or periodic increment (e.g. BA5) would reflect this change, while ER would.

In the second phase of the analysis, multiple regression was used to determine the relative amount of variation in ER that could be explained by PT, DBH, CR, SA, and BA5. Observations were adjusted to account for the effect of stand and treatment. The effect of stand on ER was not significant; however, the effect of thinning was highly significant [$p<0.0001$ (Table 2)]. PT and CR were also highly significant ($p<0.001$), but of lesser consequence in explaining variation in ER. DBH was not significant in this model after accounting for the variation in ER that was due to PT. This result supports Carter and Blanchard's (1978) contention that DBH is only transitively related to ER through its strong correlation with PT.

Table 2. Multiple regression of electrical resistance (ER) on phloem thickness (PT), diameter breast height (DBH), crown ratio (CR), sapwood area (SA)

Dependent variable = ER
Explanatory variables = PT, DBH, CR, SA, S1-S20, X1-X20, INT

PARAMETER ESTIMATES AND STANDARD ERRORS

	DEPENDENT VARIABLE	
INDEPENDENT		ER
VARIABLE	COEF.	SE
MPT	-1.78	0.46
DBH	0.21	0.18
CR	-49.81	14.92
SA	-0.89	0.24
STAND		
INT	159.55	11.50

---------- ANALYSIS OF VARIANCE TABLE ----------

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	F-RATIO	P-VALUE
Total	438	1019789.35			
PT	1	14456.75	14456.75	14.7817	0.0001
DBH	1	1257.34	1257.34	1.2856	0.2575
CR	1	13206.09	13206.09	13.5029	0.0003
SA	1	65868.48	65868.48	67.3491	0.0000
STAND	19	291348.44	15334.13	1.2399	0.3183
TRMT W/IN STAND	20	247336.02	12366.80	12.6448	0.0000
Error	395	386316.23	978.02		

R-square = 0.621

Fitted values for the mean of the dependent variable, ER, are shown in Table 3 for a representative stand (stand 9). The relative differences in ER between the thinned and adjacent unthinned stand, and between the first quartile, median, and third quartile of the explanatory variables, provide a useful indicator of how ER varies between treatments and over a range of PT, DBH, CR, and SA. Differences in fitted values of ER were modest between the first quartile, median, and third quartiles of the explanatory variables, but were large between the thinned and unthinned stands.

Table 3. Fitted values for the mean of the dependent variable, electrical resistance (ER), for a representative stand (stand 9).

					THINNED			UNTHINNED		
	PT	DBH	CR	SA	LB	EST	UB	LB	EST	UB
Q1	6.5	5.4	0.3	11.7	107.8	146.7	185.5	187.3	212.5	237.7
MED	7.5	6.7	0.4	16.9	100.3	139.3	178.3	179.9	205.2	230.5
Q3	8.5	7.7	0.5	22.1	92.5	131.7	170.8	172.0	197.6	223.1

In the third phase of the analysis, observations on the five vigor variables (ER, PT, CR, SA, and BA5) were subjected to principal components analysis. In the unthinned stands, 57 percent of the variation in these variables was accounted for in the first component axis, although relatively little of it was associated with ER (Table 4). The variation accounted for in the first axis was approximately evenly divided among PT, CR, SA, and BA5, suggesting that these four measures may be at least somewhat interchangeable indicators of tree vigor. An additional 19 percent of the variation was accounted for in the second component axis, the vast majority of it by ER. A preponderance of the variation in these five variables (76 percent) was accounted for in only two component axes. Variation associated with ER was apparently distinct from that associated with the other four variables that reflect some aspect of tree vigor. CR, PT, and SA could be viewed as moving average indicators of vigor, whereas ER might better be considered as a current (or instantaneous) measure of vigor. This finding supports Cole's (1980), Gagnon et al.'s (1987), and MacDougall et

al.'s (1987) observation that ER varies with daily and seasonal environmental changes, and unlike CR, PT, and SA, is especially sensitive to water potentials and water stress. It also suggests that traditional mensurational measures cannot fully describe tree vigor, because all substantially lag current growth performance and tree vitality.

Table 4. Results of the principal components analysis of five vigor variables in the unthinned stands.

Correlation matrix (stand accounted for)
N = 182

	ER	PT	CR	SA	BA5
ER	1.000	-0.224	-0.153	-0.354	-0.265
PT	-0.224	1.000	0.651	0.608	0.565
CR	-0.153	0.651	1.000	0.472	0.325
SA	-0.354	0.608	0.472	1.000	0.800
BA5	-0.265	0.565	0.325	0.800	1.000

	Percent Variation Explained	E-value	Coefficients ER	PT	CR	SA	BA5
1st Axis	57.205	2.860	-0.263	0.496	0.414	0.526	0.486
2nd Axis	18.548	0.927	-0.806	-0.294	-0.480	0.124	0.139
3rd Axis	14.556	0.728	-0.522	0.163	0.534	-0.313	-0.564
4th Axis	6.228	0.311	-0.043	0.787	-0.506	-0.349	-0.018
5th Axis	3.463	0.173	0.085	0.145	-0.241	0.699	-0.652

Correlation of variables and principal components

Variable	Component 1	2	3	4	5
ER	-0.445	-0.776	-0.446	-0.024	0.036
PT	0.839	-0.283	0.139	0.439	0.060
CR	0.700	-0.462	0.455	-0.282	-0.100
SA	0.890	0.119	-0.267	-0.195	0.291
BA5	0.823	0.134	-0.481	-0.010	-0.271

In the thinned stands, 46 percent of the variation in ER, PT, CR, SA, and BA5 was associated with the first component axis, and the variation accounted for was again approximately evenly divided among PT, CR, SA, and BA5 (Table 5). An additional 23 percent of the variation was accounted for in the second component axis, the preponderance of which was associated with ER. Variation associated with ER in the thinned stands again appeared to be distinct from that associated with the other four vigor variables.

Table 5. Results of the principal components analysis of five vigor variables in the thinned stands.

Correlation matrix (stand accounted for)
N = 245

	ER	PT	CR	SA	BA5
ER	1.000	0.134	0.239	0.128	-0.173
PT	0.134	1.000	0.418	0.336	0.229
CR	0.239	0.418	1.000	0.493	0.428
BA	0.128	0.336	0.493	1.000	0.609
BA5	-0.173	0.229	0.428	0.609	1.000

	Percent Variation Explained	E-value	Coefficients ER	PT	CR	SA	BA5
1st Axis	45.913	2.296	0.128	0.411	0.526	0.548	0.487
2nd Axis	23.441	1.172	-0.822	-0.226	-0.182	0.113	0.476
3rd Axis	14.750	0.738	-0.394	0.836	-0.028	-0.312	-0.221
4th Axis	9.610	0.480	-0.207	-0.265	0.810	-0.477	-0.060
5th Axis	6.285	0.314	-0.330	-0.109	0.183	0.602	-0.696

Correlation of variables and principal components

Variable	Component 1	2	3	4	5
ER	0.195	-0.890	-0.338	-0.144	-0.185
PT	0.623	-0.244	0.718	-0.183	-0.061
CR	0.797	-0.197	-0.024	0.562	0.102
BA	0.831	0.123	-0.268	-0.330	0.337
BA5	0.738	0.515	-0.190	-0.042	-0.390

DISCUSSION

ER was moderately to highly correlated with traditional measures of tree vigor (e.g. PT) within a given stand. However, both the slopes and intercepts of these correlations varied considerably among stands. Hence, the correlation coefficient for the combined data set (20 stands) was essentially zero. This result strongly suggests that measurement of ER for comparative purposes be restricted to use within a stand, or between adjacent stands, where variation in observations due to time of day, season, site quality, and perhaps genetic ecotype can be minimized.

Based on this regional study, ER does not appear to be a robust measure of tree vigor because of its sensitivity to other stand, site, and temporal factors. However, results of the principal components analysis suggest that ER provides a current measure of vigor that is not reflected in such traditional measures as CR, DBH, PT, or SA.

Delayed manifestation of vigor may not be especially significant if gradually increasing competition brings about a gradual reduction in growth; however, it may be a critical deficiency when assessing tree vigor from the standpoint of pest (e.g. mountain pine beetle) resistance. For example, while tree moisture stress may not be visually apparent, it reduces oleoresin production potential, exudation pressure and duration of flow (Lorio and Hodges 1977). Reduced water potential and

resin status (production and exudation pressure) in turn reduce resistance to beetle attack.

Kaufmann and Watkins (1990) propose a physiological basis for assessing lodgepole pine vigor that includes such factors as leaf area, sapwood area, age, and incremental growth rate. They suggest using these factors to define a high- to low-vigor continuum, rather than placing trees in discrete groups based on visual appearance. Results of this study suggest that ER may also have utility for assessing lodgepole pine vigor, since it provides a current and distinctive measure of physiological status.

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